Dynamic models for plasma-wall interactions

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The plasma-wall interactions play important roles in current tokamaks and they are vital for the next-step fusion energy devices (e.g. ITER). In theory and modeling of plasma-wall interactions, very different spatial and temporal scales need to be resolved. A hierarchy of "wall" models (e.g. macroscopic transport, Kinetic Monte Carlo, Molecular Dynamics, and quantum models) and plasma models corresponding to different scales will be reviewed. The integration of these models will be discussed.

Characteristic processes in plasma-wall interactions (e.g., absorption, sputtering, backscattering, implantation, reactions, diffusion/advection, trapping, sublimation, and co-deposition) and established formalism will be discussed within the framework of macroscopic transport models for hydrogen isotopes in materials (e.g. WALLPSI code). As validation example, results on dynamics of chemical erosion, radiation enhanced sublimation, and hydrogen retention for fusion related materials will be presented. Macroscopic transport codes for material coupled to plasma transport codes give initial capabilities of self-consistent modeling.

More detailed picture of plasma-material interactions, varying material structure, composition and chemistry gives atomistic approach. We start from well-ordered, crystalline surfaces then follow the surface evolution and damage produced by the cumulative bombardment of the surface by hydrogenic particles, by the combination of plasma exposure and beam-like irradiation. The short time and length scales where atomic collisions and chemical reactions take place are described using an MD formulation employing complex many-body potentials, both classical and quantal density-functional tight-binding (DFTB) versions. Appropriate reactive bond order classical MD potentials and parameterizations for the DFTB MD have been developed or adapted from the literature. Validation of our approach was achieved via closely coordinated ion-beam-target studies. The results on C-H, Li-C-O-H and W-Be-C-H mixed materials systems will be presented.

Edge plasma transport is well known to be highly intermittent and non-diffusive via coherent structures (so-called blobs and ELM filaments) moving ballistically to walls. This intermittent transport has strong impact on both edge plasma parameters and plasma-wall interactions. A new "macro-blob" approach to simulate simultaneously the edge plasma transport, statistical turbulent properties, and wall dynamics within the framework of 2-D edge-plasma fluid transport code has been developed and implemented into UEDGE. The results of time-dependent modeling of bursty plasma and wall with improved UEDGE and WALLPSI codes will be presented. The effect of macro-blobs on background plasma, impurity dynamics, and hydrogen recycling will be discussed. Comparison between static and transient power loads as well as sputtering rates for material surfaces will be given. Parametric analysis of wall response (e.g. temporal evolution of hydrogen inventory in the wall, wall temperature, erosion, and hydrogen out-fluxes) to plasma bursts with WALLPSI code will be presented. Characteristic times for the release of particles deposited during the bursts into the wall will be analyzed and the role of wall out-gassing in pedestal recovery from blobs and ELMs will be highlighted.